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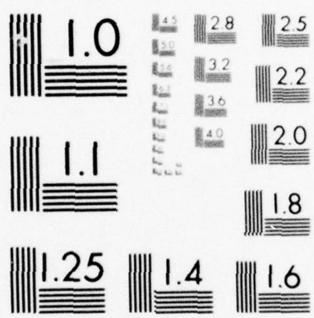

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AVIATION RESEARCH LABORATORY

INSTITUTE OF AVIATION
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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TECHNICAL REPORT

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HUMAN PERFORMANCE IN AVIATION SYSTEMS

Final Report

ARL-77-14/AFOSR-77-12
JULY 1977

PREPARED FOR

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

AVIATION RESEARCH LABORATORY

INSTITUTE OF AVIATION

University of Illinois at Urbana-Champaign
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61874

FINAL REPORT

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FOREWORD

This Annual Report on Contract No. F44620-76-C-0009, "Human Performance in Aviation Systems," summarizes research performance and results and related accomplishments during the period 1 July 1975-30 June 1977. Detailed accounts of the research are published in technical reports and scientific journal articles. These are listed in this report.

Dr. Alfred R. Fregly, Life Sciences Directorate, Air Force Office of Scientific Research was the Program Manager for the Air Force. Dr. Charles O. Hopkins, Head of the Aviation Research Laboratory, University of Illinois was the Principal Investigator. Dr. Stanley N. Roscoe served as Co-Principal Investigator during the last six months of the year.

This report represents the end of a seven-year period of highly productive research programs sponsored by the Air Force Office of Scientific Research and other agencies at the Aviation Research Laboratory. All of the faculty and staff members of the Aviation Research Laboratory, with the exception of one relatively recently hired person, are transferring to other departments in the University of Illinois. However, the name "Aviation Research Laboratory" will reside with the Institute of Aviation.

Research on some of the problem areas that have been investigated by the staff of the Aviation Research Laboratory during the past several years will be continued by these people in their new positions. It is planned that the persons transferring out of the Aviation Research Laboratory will be joined by other University of Illinois faculty

members (notably from the Departments of Industrial Engineering, Electrical Engineering, and Mechanical Engineering to form the nucleus of a new human factors research laboratory to be located on the main campus of the University of Illinois at Urbana-Champaign.

TASK 1 ATTENTION, TIMESHARING, AND PILOT PERFORMANCE

The purpose of this task was to investigate the effects of divided attention on the human operator's failure detection, decision making and control capabilities, and to try to identify the nature of performance changes under dual-task conditions. A related question addressed in this research was whether dual-task performance could be described as a trainable transferrable skill. Four separate areas of experimental research were performed during the contract period.

Effects of Participatory Mode and Workload on the Detection of Dynamic System Failures

The objective of this experiment was to determine whether the human operator is more sensitive to control system failures as an active participant in the control loop of an aircraft or as a monitor, observing an auto pilot performing the control task. In addition, it was of both practical and theoretical significance to determine how the relative merits of control vs monitoring in detection were affected by changes in concurrent task workload.

A theoretical analysis of the failure detection process was first undertaken in an effort to identify variables that might differentially influence detection performance in the two modes. Considerable effort was also devoted to developing a failure detection analysis methodology by modifying techniques borrowed from signal detection theory and speed-accuracy analysis. Finally, a large portion of the contract period was devoted to developing, programming, and optimizing the particular

detection paradigm to be employed on a Raytheon 704 computer. This involved the conduct of three experimental pretests, which provided the basis for selecting variables employed in the main experiment.

In the experiment, human subjects detected step changes in the control order of a dynamic system, simulating the loss of stability augmentation. Detection was required under control and monitoring conditions. In addition to single-task condition, subjects performed the tasks while timesharing performance with a critical tracking task at either of two difficulty levels. While additional data are currently being collected, an interim analysis of the data collected on three subjects suggests that under single-task conditions, the operator is more sensitive to failures as a monitor than as a controller. This superiority was manifest in terms of increased accuracy with no decreases in detection latency. However, as concurrent task demands were imposed, autopilot detection deteriorated to a greater extent than did control detection. A detailed analysis of the operator's control response to failures was then undertaken in order to assess the cues upon which detection decisions were based. A replication of this experiment is currently in progress, incorporating some changes in order to provide greater generality of the conclusions. The results of this experiment were presented at the thirteenth annual conference on manual control in Boston.

Expectancy and Failure Detection

A criticism occasionally voiced of many failure detection experiments is that the relatively high frequency of failures, necessary to obtain sufficient data for statistical reliability, produces an expectancy of failure on the part of the subject quite different from that experienced in normal flight, when normal operation is expected. The purpose of this experiment was to explicitly manipulate the subject's expectancy of failure occurrence in order to determine if expectancy changes influenced the response to failures. Two primary conditions were contrasted. In the unexpected condition, failures were introduced on a tracking trial in which subjects had no prior knowledge that failures were to be introduced, or even that they were being investigated in the experiment. In the expected condition, subjects were told prior to the trial that a change in system dynamics would occur. Since subjects made no overt detection in either case, their response to the failure was assessed by examining ensemble averages of control stick and tracking error records. On the basis of data collected from 30 subjects, it was tentatively concluded that, within the range of expectancy employed, the effect of the expectancy variable on control adaptation to failure was slight, and that the control response did not appear to be qualitatively different in the low and high expectancy conditions. This result is encouraging, suggesting that it is possible to generalize results from the high expectancy conditions, typical of most failure detection research paradigms to the low expectancy conditions, typical of a pilot's in-flight environment.

<u>Adjustments to Changing Task Priority in a Timesharing Environment</u>

Results of previous research at the Aviation Research Laboratory suggested that an operator's ability to reallocate his processing resources between tasks according to changing task priorities is an important variable that could be employed to predict pilot performance. Whereas in the previous research, task priorities were manipulated <u>between</u> sessions, the current investigation manipulated priorities in a dual-axis tracking task <u>within</u> a tracking trial. Priorities were manipulated indirectly by varying the difficulty of the primary task while requiring that its performance level be held constant. This manipulation forces a reallocation of resources to compensate for difficulty changes. The multiple objectives of this study were: (a) to model this dynamic resource reallocation process and determine its characteristics, (b) to evaluate the usefulness of the feedback bar graph technique, developed by Gopher in this Laboratory under previous AFOSR contract support, in assisting the operator to monitor his own performance, and (c) to investigate the sensitivity of an on-line measure of open-loop tracking gain to difficulty-induced changes in operator resources allocated to the tracking task. This third objective derives from the results of previous research by Gopher and Wickens.

Eight subjects performed two concurrent tracking tasks under conditions of either constant or variable difficulty. In the variable conditions, the second order component of the primary task dynamics was driven by a low frequency quasi-random input. This input simulated periodic changes in task demand and, therefore, induced changes in the attention required to maintain constant primary task performance.

Data analysis is currently in progress. We are evaluating tracking error as a function of task practice, variable vs constant difficulty, and the availability of performance feedback. Quasi-Linear modeling techniques are applied to evaluate the performance response on both tasks to difficulty variation, thereby to determine the characteristics (time-lag, linearity, gain) of the reallocation process. Upon completion of data analysis in the present study, a second study will be undertaken that will change the characteristics of the variable difficulty forcing function. It is anticipated that the paradigm developed will provide a useful measure to assess the reallocation skill that can be employed in pilot prediction studies.

The Acquisition and Transfer of Timesharing Skills

A common finding of many experiments has been that performance under divided-attention conditions improves with practice. This improvement often has been attributed to development of timesharing skills. However, none of the methodologies used in these studies partitioned the improvement in performance found with practice into a component due to improved single-task skills and a component due to improved timesharing skills. As a result, there is little clear evidence for the existence of timesharing skills. A systematic exploration of these skills has not been undertaken previously. The purpose of this study was to determine, through examinations of the literature and experimental investigation, if practice in a dual-task environment leads to the acquisition of a unique timesharing skill that may be distinguished from improvement on component tasks. To the extent that such a skill is identified, two

further questions can be asked: (1) What is its precise nature (e.g. is it parallel processing, rapid intertask switching, independent processing)? (2) Is it a general skill that will transfer between qualitatively different dual-task combinations?

Forty-eight female subjects participated in a transfer of training design. On Day 1 an experimental group received practice in a timesharing combination of two discrete digit processing tasks (classification task and short-term memory task). A control group received identical practice on Day 1 except that the two tasks were never performed concurrently. On Day 2, both groups, along with a third group which had received no training on Day 1, performed a dual-task tracking combination.

Analysis of performance acquisition indicated the development of timesharing skills on both task combinations. A fine-grained performance analysis suggested that in the digit task combination this was a parallel processing skill. Some evidence was also provided for the transfer of the skill to the qualitatively different tracking-tracking combination. Control theory analysis revealed that in this combination, subjects similarly acquired a skill in parallel processing. This analysis indicated an increase in linear coherence and open-loop gain along the ipsi-lateral tracking axes (right error-right response, left error-left response). Furthermore, evidence was provided that it was this parallel processing skill, acquired under the digit task combination that transferred to the tracking combination, and thus produced the initial superiority in performance of the experimental group. The results of the control theory

analysis of the timesharing skill were presented at the thirteenth annual conference on manual control in Boston. The results of training and transfer portion will be presented at the twentieth annual meeting of the Human Factors Society in San Francisco.

TASK 2 TRANSFER OF COMPUTER ASSISTED LEARNING TO FLIGHT

The ground school class and perhaps the ground-based trainer or simulator comprise the primary ground training tools generally employed in the modern pilot training curriculum. When these tools are optimally used, efficiently integrated, and coupled with appropriate instruction, an acceptable magnitude of transfer to the actual aircraft can often be realized.

The magnitude of this transfer is generally related primarily to the transfer effectiveness of the ground-based trainer. And, the modern trend has been toward the development of trainers which seek to duplicate every sensation of flight. However, a direct causal relationship between this so-called "high fidelity" of the training device and its transfer effectiveness has not been documented. Increasing fidelity is directly related, however, to increasing costs of purchasing, maintaining, and operating a trainer. Considering the possible tradeoffs between transfer effectiveness and cost, the most reasonable choice may be to adopt a training device whose transfer is less than that of a more complex and costly device.

The foundation of one such device can be found within the technology of interactive computer-assisted instruction (CAI). A CAI device aimed largely at instrument instruction has been developed. This synthetic trainer uses the PLATO interactive computer-assisted teaching system at the University of Illinois. It provides the opportunity to "fly" a simulated aircraft using a hand control and with reference to dynamic

instruments which are displayed on the plasma panel screen (similar to a CRT). Initial evaluation suggests that CAI training does result in positive transfer to the ground-based trainer (Trollip, 1977).

The present experiment was performed in order to determine:

- whether the CAI training device would yield positive transfer to an actual aircraft.
- the relative transfer and cost effectiveness of CAI training when compared with the more traditional ground-based trainer.

A total of 48 private pilots, all without prior instrument instruction in excess of that required of all private pilots, were employed as experimental subjects. They were randomly assigned to one of three training programs. These were (a) CAI, then aircraft training, (b) ground school, ground-based trainer, then aircraft training, and (c) ground school, then aircraft training. This last group served as the control group for the experiment.

The instrument maneuver that was used as the training exercise, the holding pattern, was the same as the maneuver used by Trollip (1977). The performance criteria and CAI training programs were also essentially the same. The aircraft used throughout the experiment was the complex, single-engine Piper Arrow. The ground-based trainer was the Singer-Link GAT-2 modified to resemble, in response and performance, an aircraft such as the Piper Arrow.

Analyses of variance were performed on data categorized into seven dependent measures. These measures are 100-, 150-, and 200-foot altitude errors, 5-degree and 10-degree tracking errors while flying the holding

pattern inbound leg, errors in timing the inbound leg and the number of trials to criterion.

With respect to all dependent measures, the group of students trained only by means of the ground-school class and the aircraft (the control group) performed least capably in the transfer criterion task. The groups trained on either one of the synthetic devices were statistically distinguishable from their control group counterparts in four of the seven dependent measures (150- and 200-foot altitude errors and 5-degree and 10-degree tracking errors). Trends in the data of the three remaining dependent measures all suggest the superiority of either synthetic device when compared with exclusive use of ground school and the aircraft alone. Comparing the two groups trained by synthetic means, there were no statistically distinguishable differences. However, the CAI trained group did perform better than the group which used the ground-based trainer in all categories except inbound time.

The percent transfer of both the ground-based trainer and CAI training system were of similar magnitude. The use of either training program resulted in the synthetically trained students completing the transfer task in an average of 75% of the aircraft training time that the control group students required. The value of this savings in training time can best be examined in terms of the relative costs of the training program.

An informal survey of several users suggests that the direct cost associated with the use of the ground-based trainer is approximately $20 per hour including the instructor. In addition, we added $3 per student

hour as the assumed cost of ground-school training. The cost associated with the CAI device, however, does not lend itself to a simple cost per hour analysis. Cost of CAI training is best addressed in terms of a fixed monthly fee independent of the amount of use. However, using the results of the present experiment, the two synthetic devices appear cost competitive if the CAI device is used a minimum of 58 hours per month.

In even a moderate size instrument training program, if the CAI device proves equally effective when used to teach the entire regime of instrument flight maneuvers, several hundred hours of CAI use per month would most probably be realized. The existence of on-site CAI units would also permit the incorporation of CAI training into many facets of academic aviation instruction which currently are being conducted exclusively in the classroom. Thus, there is potential for secondary cost savings above that realized by reducing the use of the aircraft or the ground-based trainer and the instrument ground school.

However, these results must be interpreted with some caution. The effectiveness of the CAI technique across the wide range of instrument maneuvers, the transfer value of the device when used in an actual instrument training program and the incremental transfer effectiveness of the device all must yet be considered. It is also possible that CAI training may best be incorporated into an overall training curriculum by utilizing a ground-based trainer of moderate fidelity coupled with the enhanced instructional and feedback capabilities of CAI technology.

TASK 3 COMPUTER ASSISTED DECISION TRAINING FOR AIR COMBAT TACTICS

Synthetic flight training devices are commonly used in training when: (a) the users wish greater control over ambient conditions, (b) dangerous elements in an operational situation may be represented safely, or (c) a reduction in training cost is desired. Synthetic training technology has proved most effective in the teaching of procedural skills and slightly less effective for teaching perceptual-motor skills. However, synthetic flight training devices have been virtually unused in the teaching of decisional skills, despite the fact that many flight operations require training on proper decision-making that can be carried out with reasonable safety only in a simulated flight environment.

Perhaps the most personally critical decision-making role in aviation is that of the air combat pilot. He must be prepared not only to control his own aircraft to the limits of its performance envelope but also keep track of the actions of any adversary representing a threat to his own survival. Although tactics for certain commonly occurring situations can be formulated in advance, the great variety of possible contingencies precludes the teaching of appropriate responses for all situations. Rather, an evaluation at the time of contact by the pilot is required, including the probabilistic prediction of adversary counteractions. These characteristics make the air combat situation an ideal one for research into tactical decision making.

However, the decisional skills required by the fighter pilot can be acquired in a number of different ways. Actual air-to-air combat undoubtably improves the decisional skills of the survivors. Various forms of

mock combat still involve considerable hazard to the operators. While the highly perceptive pilot may improve his decisional skills significantly by simply reading tactics handbooks, most fighter pilots will probably benefit most from a synthetic training environment. This is certainly the only environment in which there is sufficient control over ambient conditions for the interactions between adversaries to be accessible to scientific investigators.

Synthetic flight training equipment can be classified in many different ways, including a scheme that distinguishes between a simulator (which is similar to a specific system) and a trainer (which is similar to a class of systems). Either a trainer or a simulator may be equipped with computer graphics or it may not be so equipped. Several research efforts are already being conducted in the area of air-to-air combat tactics training under the classification of "graphics simulators." These devices are high fidelity simulators designed to reproduce as many of the cues experienced in the operational system as possible.

It is not our purpose to compete with such large-scale research and development activities. Rather, our goal is to isolate those essential decisional cues in the air-to-air combat siutation and present these to the pilot as opposed to presenting as many cues as the state of the simulation art will allow. Recent advances in computer display and memory technology allow essential cues to be presented at a very low cost. We have termed devices in this class "graphic trainers." Costs are estimated to be in the vicinity of one dollar per contact hour.

In the period of some six or eight months prior to the beginning of the work on this contract task during the 1976-77 contract year we gained considerable experience in this area by developing a preliminary program on the PLATO system using a standard terminal. The program allowed competition between two persons seated at different controls. Each person could control one of the airplanes depicted on the display screens. Each player in this air-to-air combat simulation controlled in discrete increments, the airspeed, pitch, rate-of-roll, and release of armaments for his aircraft. The flight parameters for each plan, such as top speed, ceiling, etc., were easily modifiable in the program, thereby, facilitating the representation of a number of different aircraft types. While the standard PLATO terminal was satisfactory for a demonstration program, a more sophisticated terminal design was required to provide the versatility needed for the research program.

During the past year, the computer hardware required for a sophisticated terminal to support decision training for air combat tactics either was purchased from commercial sources or was designed, constructed, and checked-out. The major purchased items were a PDP 11/10 minicomputer with 8K core memory and a parallel plasma panel. The constructed items included a display controller, a communications-keyset-touch panel interface and a programmable read-only memory.

Initial design work on some constructed items was done under other support. For our task these designs were modified for optimum use within our limited resources.

In addition to the hardware development, intelligent terminal software was acquired to support the decision-training application. Modification to this software will be required before it can be used.

A block diagram of the system is shown in Figure 1. The display controller enables the PDP 11/10 minicomputer to drive a parallel plasma display panel. This controller, the most advanced of its type, permits hardware-segmented vertical vectors of up to 16 dots to be displayed in 20 microseconds, fast enough to support the complex real-time displays useful for decision training.

The communicatons, keyset, and touch panel interface accepts input from the user and permits the PDP 11/10 minicomputer to communicate with the PLATO computer-assisted instruction system. This capability enables the decision training application to take advantage of both the high-level instructional software support provided by PLATO and the real-time processing capabilities of a dedicated minicomputer. The debugging of this interface turned out to be more involved than originally envisioned due to errors in the original design performed by others. However, it is now operational.

A programmable read-only memory was developed to promote ease of use of the decision training terminal. Without this feature, a decision training terminal must download the appropriate programs before each use. Commonly used routines are instantly accessible with this feature.

This development effort has resulted in a low cost, yet sophisticated computer graphics research environment in which experimental investigations can take place to isolate the essential decisional cues in the air-to-air

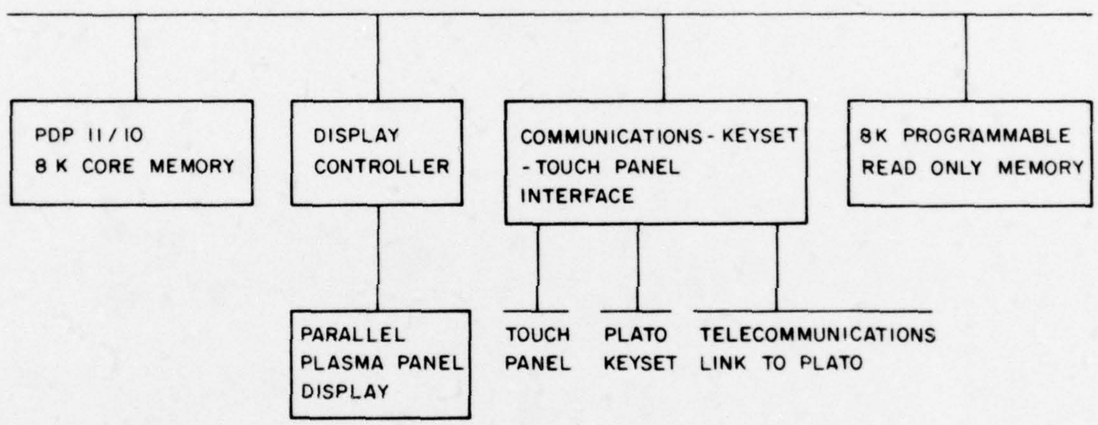

Figure 1. Block diagram of intelligent PLATO terminal for air combat tactics decision training.

combat situation. After further research has isolated these cues, the emergence of a new class of highly cost effective computer-based trainers may be possible.

TASK 4 ACQUISITION AND TRANSFER OF AIRCRAFT LANDING SKILLS THROUGH MANIPULATION OF THE AUGMENTED CUE STRUCTURE

Learning to land an aircraft is one of the most dangerous and, for some, frustrating phases of flight training. The new generation of flight simulators that the Air Force expects to place in service within the next few years will allow trainees to practice landing safely. The frustration associated with this phase of flight training will not be eased however unless the distinctive capability of simulation to provide a learning experience different from that provided in the air can be exploited. Some training manipulations that are feasible only in a simulator could moderate the time consuming trial and error process of learning and integrating the correct perceptual cues and motor responses that are required for landing an aircraft.

Landing an aircraft is an example of the classic perceptual-motor skill in which the operator must learn to integrate motor responses with perceptual cues. Throughout the approach and landing, a pilot must judge the actual and desired flight paths and attitudes of his aircraft from imprecise cues. He must further be able to achieve and maintain the correct flight path and aircraft attitude. Although the perceptual and motor components of this skill are conceptually distinct, they are functionally interdependent. During normal training, the pilot's opportunity to practice the correct control movements depnds on his ability to make the correct perceptual judgments. Conversely, his opportunity to experience the correct perceptual cues depends on his ability to control the aircraft.

Landing skills are, therefore, acquired through a trial and error process in which mastery of each component of the task increases at a rate that is limited by the current mastery of the other component. The trial and error process might be avoided by temporarily eliminating or simplifying either the perceptual or the motor component of the task. With one component of the task eliminated or simplified, the trainee might learn the other component more quickly. When he had demonstrated competence on that component of the task, the other component could be changed back to its operational form so that the trainee could learn the total task.

The landing task could be simplified by removing the control requirement. However, a previous attempt by Adams and Hufford in 1961 to teach perceptual cues in the absence of control requirements, by showing films of the approach and landing, was unsuccessful. The open-loop nature of the initial training experience provided in this experiment was probably a critical factor. The particular difficulty with a training paradigm that initially uses the open-loop mode is that, at the time of transferring to the closed-loop mode, the trainee must associate the newly learned stimuli with different responses. According to Osgood's transfer of training surface, pairing dissimilar responses with similar stimuli will interfere with learning and lead to negative transfer. On the other hand, Osgood also suggests that pairing similar responses with dissimilar stimuli will lead to positive transfer.

This latter principle can be applied in closed-loop perceptual-motor training in which the motor component is first taught with an augmented

visual display that guides the trainee towards the correct control behavior. After the trainee can execute the appropriate motor behavior in the presence of the augmented display, he would be called upon to reproduce it in response to a display that more closely approximated the perceptual scene available in flight. Although Osgood developed his principles of transfer from results in verbal learning, data from investigators in the Aviation Research Laboratory indicate that the same generalizations apply to motor learning. Thus the closed-loop approach would almost certainly be more effective than the open-loop design tested by Adams and Hufford.

Adams' closed-loop theory of motor behavior assumes that an internal representation of a response pattern develops as the response is practiced. The internal representation, when established, can guide skilled behavior. Consistent relations between responses and response error information are essential for the internal representation to be strengthened with practice. Thus, open-loop practice, where error information is unrelated to the operator's control movements, is likely to interfere with skill acquisition; whereas closed-loop practice, where error information is generated by the operator's responses, should facilitate skill acquisition. According to Adams' theory, the closed-loop training suggested in this proposal should speed skill acquisition because it will ensure a consistent relationship between control behavior and error information. The strong empirical foundation of the closed-loop theory enhances its support of the proposed training manipulation.

The perceptual component of the landing task could be simplified in a simulator by providing more precise visual cues than are normally available. As demonstrated by recent work at the Aviation Research Laboratory (Eisele, 1976, in preparation) supplementary visual information can improve a pilot's perception of aircraft position error in the approach to landing. The presence of the supplementary command guidance cues could guide the trainee towards the correct behavior and should speed his acquisition of the correct control skills. When the trainee has learned the necessary control skills, the supplementary visual cues could be withdrawn so that he would be forced to depend upon the normal cues. A recent experiment suggests, however, that the supplementary cues will have to be withdrawn carefully.

Data from that experiment showed that subjects could develop such dependence on visual cues during motor skill learning that their subsequent performance on the task in the absence of visual cues was poorer than that of subjects who were not allowed the visual cues during the acquisition phase. Thus, a one-stage withdrawal of the supplementary cues provided for the landing task is likely to disrupt the motor component of the skill. A fading technique that allows gradual withdrawal may be more successful. Schedules that present the supplementary cues only when the trainee exceeds an error criterion will be tested. Such a fading technique should reduce the trainee's dependence on the supplementary cues without disrupting his newly learned motor skill.

The flight characteristics of a highly modified Singer-Link general aviation trainer have been programmed to approximate those of a Piper

Cherokee Arrow. A visual display for the trainer had been constructed from an Advent Videobeam 1000 projection television system. The TV projector is mounted on the cockpit roof of the simulator and the 178 x 135 cm screen placed approximately 224 cm in front of the pilot's viewing position. Dynamic imagery, generated on a 21.5-cm square plasma-matrix display panel by a PDP-11/40 computer is transferred to the television projector via a Panasonic WV-350P television camera. Films and audio tapes covering basic aerodynamics and flight maneuvers have been loaned by Jeppesen-Sanderson for the ground-school instruction. A Norelco Model LCH 2020 variable motion projector, loaned by Phillip's Audio Video Systems is used to project and play the films and tapes.

A performance scale, in the form of a booklet that contains instructions to guide the experimenters and safety pilots through the training sequence and to rate the subjects on selected maneuvers, was developed following procedures developed on a previous AFOSR sponsored research task at the Aviation Research Laboratory. Taped instructions for each maneuver are played to each subject before he first practices that maneuver. Subjects receive written instructions for basic flight maneuvers during their first lesson. In addition, they are assigned readings and questions from a workbook developed for the experiment.

Four groups of randomly allocated, flight-naive subjects are being trained in accordance with an abbreviated flight syllabus. The first two lessons are used to test flight aptitude and to teach theory and techniques of flight. Student pilot subjects then learn non-contact flight maneuvers in a modified Singer-Link general aviation trainer

that has a visual landing display attached (GAT/VLD). In the fourth lesson students again receive instruction in the GAT/VLD under one of the experimental treatments.

The fourth lesson is the only one in which instruction differs for the four groups. One group practices a compensatory tracking task in the GAT/VLD. Students have to progress through a descent, level-off, and stall to perform the tracking task successfully. A second group practices landing the GAT/VLD with reference to a closed-loop visual display of a runway and centerline. A third group, designated the <u>constant augmented feedback group</u>, practices landing the GAT/VLD with visual display which has, in addition to the runway and centerline, command guidance cues that show the subject when he is off the desired flight path during the approach and too high during the flare (Figure 2). A fourth group, the <u>off-target augmented feedback group</u>, practices landing the GAT/VLD with a display similar to that used by the <u>constant augmented feedback group</u>, except that the command guidance cues appear only when the student pilot deviates from a specified performance criterion.

Transfer performance is measured in the fifth and subsequent lessons. All subjects transfer from their experimental condition to a condition similar to that experienced by the second (closed-loop) group in the fourth lesson.

Flight performance data are collected independently by a flight instructor and an observer. Instructors advise or assist a student during the course of a rated trial, only on aspects of the trial that have already been checked as errors.

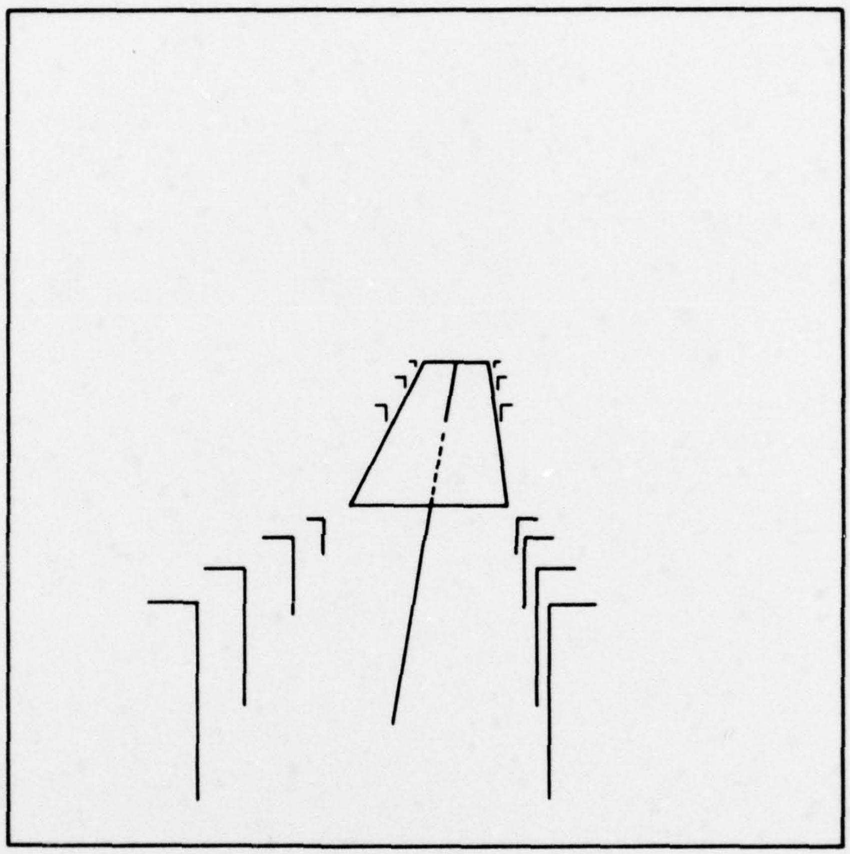

Figure 2. VLD with runway, extended centerline and approach and flare guidance cues.

Pretesting performed during the Spring of 1977 indicated that supplementary cues of the type being used in the experiment do aid approach and landing performance while present. There were also indications in a transfer test that an off-target augmented feedback schedule produced greater transfer of training than did the training without augmented feedback. Data collection on the main experiment started on 28 May 1977 and will be completed in August 1977.

TASK 5 SYNERGISTIC DISPLAYS FOR COMPLEX NAVIGATION AND CONTROL TASKS

Improvement of Air Force operating capability for precise navigation and control on complex flight paths is required both for civil operations in high density terminal areas of the future and for military operations including weapon delivery, rendezvous, penetration, or search and rescue. The need for this additional capability is being driven by simultaneous requirements for increases in the safety, efficiency, and capacity of the ATC environment and by increasingly stringent navigation, command, and control demands for very complex flight paths being used in military missions. Considering the increased demands that these additional requirements place upon the human operator, an optimized pilot-aircraft interface is necessary. A synergistic aircraft information display system could facilitate interaction of the pilot with the aircraft and its environment with a related reduction in pilot workload. This synergistic aircraft display concept consists of five basic system functions: parametric, graphic, predictive, integrative, and interactive.

The parametric function is the one most frequently encountered in current aviation displays. It consists of status indications of vital system and flight variables, such as fuel level, engine temperature, oil pressure, radio frequency, airspeed, and altitude. This is the most elementary type of information presentation and requires simply a numerical readout. With computer assistance, out-of-tolerance indications from these sources could be flagged and presented on the primary navigation display system, thus avoiding the necessity for frequent complex scanning of conventional instrumentation systems.

A graphic, or pictorial, display attempts to represent, on a two-dimensional surface, the geometric orientation of the aircraft in a three- or four-dimensional world. This category can be subdivided into two types, vertical-situation or forward-looking displays and horizontal or map displays. Vertical displays represent aircraft attitude and displacement in azimuth and elevation by projecting the aircraft, the terrain, airway system, or flight plan beneath the aircraft (Carel, 1965). The horizontal display may also present the desired position in the horizontal plane at some future time (Δ t) thus providing the fourth dimension.

The predictive function is one of the most useful display cues for manual tracking. This cue permits the pilot to see almost immediately the effect of any control change he makes so that he can modify his control inputs appropriately before they take full effect. Predictive indications of successive future states are generated by a fast-time dynamic model of the flight path that would result if the present control inputs are not changed. Predictive calculation solve the flight equations for a short time into the future based on the current state of all flight parameters.

The integrative function refers to the concept of presenting information from several sources pertinent to the task on the same display. This term may be used to refer to all of the previously discussed synergistic display functions, but in navigation displays there are some additional necessary information requirements. These include aircraft heading, command heading, and an expanded scale course deviation indicator, range, and command position or speed guidance.

The interactive display provides more than simple information transfer by utilizing the computational and storage capabilities of the airborne computer system. Such displays allow the operator to communicate with the computer system through input devices associated with the display such as keysets, hand controls, light pens, or touch panels. An interactive display system is useful in checking out indicated malfunctions through the various subsystems, in triggering weapons systems, and in interacting with automated airborne or ground communication systems. However, perhaps the greatest benefit provided by interactive displays is in the optimization of navigation data entry procedures.

Because of the demand for precise navigation on complex flight paths, area navigation (RNAV) techniques are required. These techniques refer to the concept of precise navigation unrestricted by the location of ground stations. Sources from which RNAV systems may draw their information include ground stations such as VOR/DME, LORAN, TACAN, and OMEGA, airborne inertial platforms, and ground radar passed to the pilot by the controller. Although the basic RNAV technique is not new to the Air Force, new system demands create a number of problems which may be amenable to solution with the present day technology.

One of the most serious of these problems is cockpit confusion which often occurs as a result of placing responsibility for RNAV waypoint location in the hands of the pilot. In conventional navigation the position of fixes to or from which the pilot flies are fixed and there is little uncertainty concerning the geographical position of the aircraft. However, in RNAV the pilot has the responsibility for setting the locations of these fixes. This additional responsibility places the pilot another

step away from the real world in which he is flying. Unless some means of direct waypoint entry confirmation and flight progress monitoring are available, the RNAV pilot will be flying in a dream world of phantom stations related to the real world only in terms of less-than-certain waypoint coordinate numbers.

Recent aircraft and simulator experiments at the University of Illinois have shown that large numbers of procedural errors occur even after pilots become familiar with the RNAV system and the flight task. In three-dimensional or vertical area navigation (VNAV) aircraft experiments, these errors occurred at a rate of approximately three errors per 100 procedural operations. Undoubtedly, many of these errors would have occurred even if the pilot had been absolutely certain of his geographical position. However, on several occasions procedural errors were a direct result of position uncertainty. The majority of the remaining procedural errors appeared to be a function of difficulty in identifying waypoint positions. A method of identification which was more direct than the comparison of entered reference numbers with chart-specified numbers would have undoubtedly eliminated most of these errors. In addition, it is probable that tracking errors (horizontal, vertical, and airspeed) increase during periods when aircraft position is uncertain because the pilot must increase the scope of his attention to determine aircraft position.

In most future Air Force applications of area navigation, whole flights will be preprogrammed on the ground prior to takeoff and flown almost entirely using the autopilot. In this case cockpit procedures

and resulting workloads will be very similar to those experienced in present-day VOR flying. However, even with this capability not all flights will be made as preprogrammed. In fact, it is safe to project that, because of less than perfect traffic, weather forecasts, or forecasts of hostile action, most RNAV flights will require impromptu waypoint insertions. Therefore, an optimum pilot interface with his aircraft and environment is required to avoid increases in cockpit workload and to avoid cockpit confusion during these demanding phases of the flight.

Several approaches have been suggested to improve the pilot/aircraft interface for complex RNAV tasks. Generally, these involve either automation of flight control functions, automation of the waypoint entry procedure, or improvement of the navigation displays. Experiments at the University of Illinois comparing waypoint storage capacities have shown that procedural errors are significantly reduced when all of the waypoints needed in the flight are entered and stored prior to takeoff. However, as mentioned above, waypoint storage does not solve the problem of impromptu changes in flight plan during the flight. These experiments also found that a reorganization of controller functions may also enhance pilot performance and residual attention.

Our approach will be directed toward the improvement of the navigation display system. Because of the higher level of position uncertainty in RNAV, the most important piece of information needed by the pilot is aircraft position relative to the geographical world. The best way to present this information is through the use of a reliable optically projected or computer-generated map display. Either of these displays may

present a variety of other navigation symbology including heading, command heading, course, course deviation, and distance to waypoint.

On the other hand, the computer-generated option is a better candidate for development as an optimum primary airborne navigation display system because it has the capability and flexibility to exploit all of the characteristics of the previously mentioned synergistic system. This system, at least intuitively, provides solutions to most of the problems found in complex RNAV tasks. The expected interface improvements applicable to these tasks include immediate geographical orientation at a glance, capability for direct scale factor adjustment, vastly reduced instrument scan patterns, malfunction alerting mechanisms on the primary display system, direct waypoint entry procedure, improved visual cues for manual tracking, and direct digital communication capability. Considering the complexity of future environments and procedures these capabilities will be essential to normal operating procedure for future aviation systems.

To study experimentally the effectiveness of alternate combinations of synergistic display variables, the Aviation Research Laboratory has developed a highly versatile computer-generated display system to present dynamic pictorial images either on a CRT or a plasma panel. Because of certain advantages over the CRT such as the absence of flicker, extended line drawing capability, and elimination of display refreshing, the plasma panel has been selected as the appropriate hardware system for this study. The pilot/computer communication capabilities of this flat-panel display have been further enhanced during this past year by the

addition of a touch panel. The touch panel is being used to eliminate the need for a physically separate keyboard. Touch points are produced by the program software and may be moved about the display as conditions warrant. The pilot need only touch the display at the desired point of modification or inquiry to initiate an entry or recall sequence.

The approach followed in the structuring and developing of an optimized navigation data entry and display system began with the analysis of navigation subtasks. Particular subtasks were examined in detail and broken down into their constituent behavioral processes. Each step was then examined and the possibilities of replacing each with simpler steps or eliminating steps altogether were assessed.

In order to illustrate this process the task of selecting a previously stored waypoint can be outlined. The pilot selects the proper functional mode for entering the waypoint for use, chooses this waypoint, enters the waypoint identifier, confirms the entry by source comparison, and returns to the base state of the system. In keyboard entry systems a short-term memory (STM) storage is required of the operator between choosing the waypoint and entering the waypoint identifier through the keyboard. Guidelines for function allocation suggest that functions requiring STM be allocated to the computer. This result was achieved in the optimized system by allowing direct entry of data through a "touch map," combining waypoint choice and entry into a single step. The intermediate data entry device (keyboard) was eliminated altogether.

At present the computer-generated interactive "touch map" is being additionally revised in accordance with principles relating to displayed information, optimally efficient input/output procedures, and both

physical and logical structure so that further reductions in operator workload and probability of operator error may be achieved. Modifications were done on-line using the PLATO IV system at the University of Illinois. The navigation display is generated on a plasma panel and uses an interfaced touch panel for direct pilot interaction with the system. The navigation program in its present state provides for data input and output for 4-D navigation and for route modifications while in flight. Map options provided include both prestored standard charts and a "make your own" option. Map alterations may take the form of waypoint insertion, relocation, or deletion. In addition to the horizontal map display the system also provides a vertical profile display depicting course vertical gradient and both aircraft location and vertical performance index.

The system has been "flown" on PLATO, both manually and automatically, by using a second program to generate aircraft status/performance parameter values which are then fed to the navigation program. In the automatic mode the computer advances to the next block of navigation data (segment in use, waypoint in use) when preset distance criteria are met, eliminating the need for manual update. To this point the "aircraft" has been manipulated by keyboard inputs. The next evaluation, however, will utilize a control stick to manipulate the aircraft as would a performance control system.

Following the final optimization of the system an analysis of its effectiveness can be made by examining the performance of pilots having either no experience or moderate experience with area navigation to

assess fully the benefits which may have been gained in comparison with performance obtained when using a system more representative of those in current use.

TASK 6 PERCEIVED SIZE AND DISTANCE AS CORRELATES OF VISUAL ACCOMMODATION

The problem of biased distance judgments encountered by pilots while flying by reference to periscopes, helmet-mounted CRT imaging displays, and either TV- or computer-generated visual systems for remotely piloted vehicles and for flight simulators has been found to be associated with oculomotor adjustments including visual accommodation as well as convergence. A review of the problem and relevant experimental evidence, with particular attention to recent findings involving the automatic measurement of accommodation while pilots were performing dynamic tasks, has been issued as Technical Report ARL-77-9/AFOSR-77-8 by Dr. S. N. Roscoe. The report, titled "How Big the Moon, How Fat the Eye?", will serve as the basis for Dr. Roscoe's invited paper as last year's winner of the Franklin V. Taylor award of the Society of Engineering Psychologists.

A technique has been developed for the measurement of accommodation to objects at great distances in open vistas by photographing the "3rd Purkinje images" reflected from the anterior surface of the lens of the eye while subjects are making size and/or distance judgments. The device is a modern adaptation of the phakoscope invented and used by Helmholtz and is referred to as a "photophakoscope." A sketch of the Helmholtz device is shown in Figure 3 which also illustrates the change in size of the lens reflections relative to the corneal reflections which do not change with changes in accommodation.

The apparatus may be considered a combination of two discrete but related sub-systems: one of which is designed to photograph unobtrusively

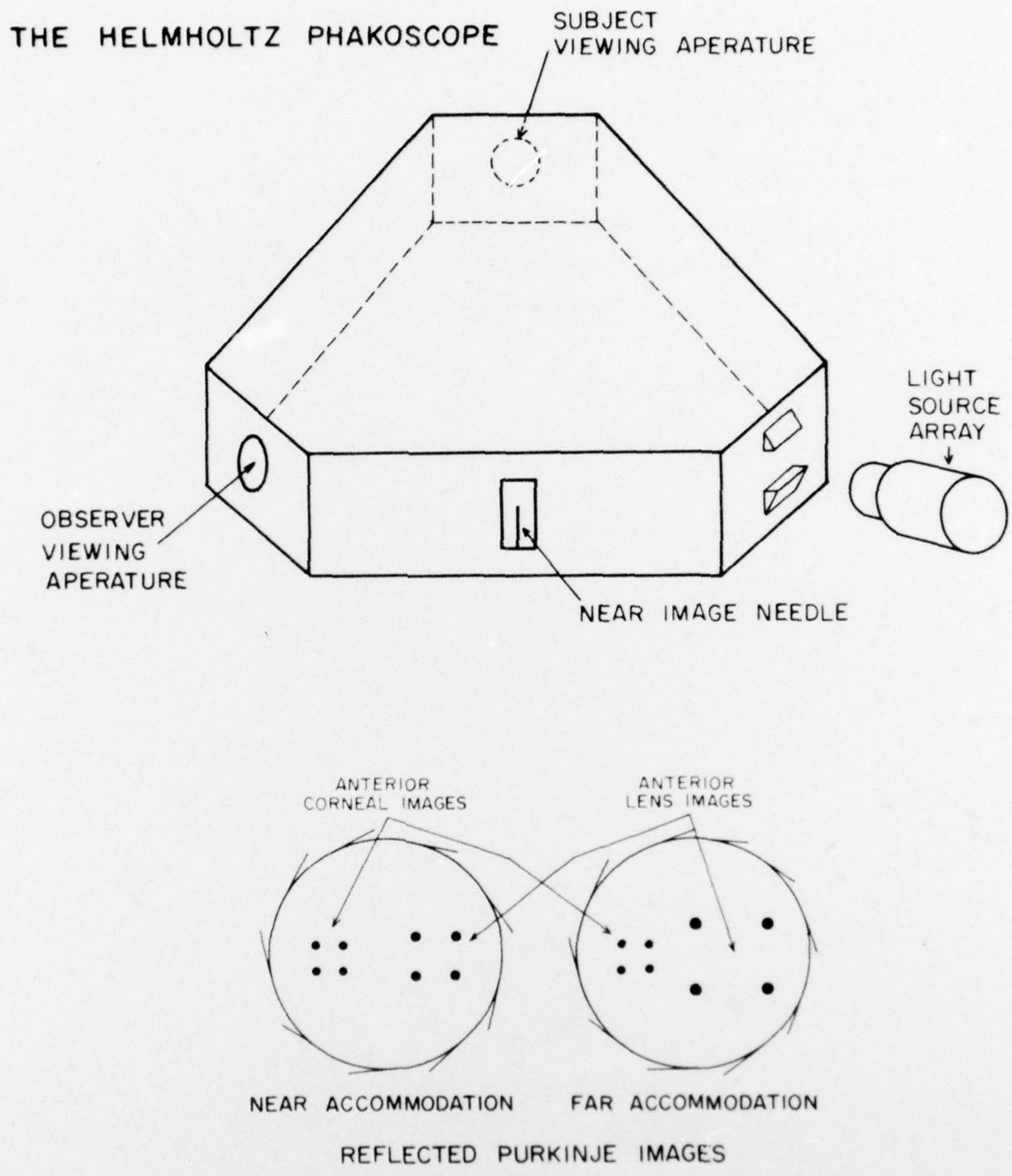

Figure 3. Sketch of the phakoscope used by Helmholtz to observe Purkinje images reflected from the cornea (1st image) and from the anterior surface of the lens (3rd image). Note that the 3rd image changes size with accommodation, whereas the 1st image does not.

an infrared image reflected from the anterior surfaces of the lens and cornea of the subject's eye: the other to provide standard and comparison stimuli superposed on a direct view terrain scene, while enabling the experimenter to occlude portions of the visual field selectively.

The photographic system is comprised of three major components: an infrared source, a prism beam splitter, and a camera, all rigidly mounted in a precision machined housing equipped with a bite board and viewing tube for accurate positioning of the subject's eye. At this time all measurement is monocular, though expansion of the system to provide simultaneous binocular measurement is both feasible and practical.

The infrared "source" is actually an array of four independent sources, each a Texas Instruments light emitting diode with a maximum rating of 300 mils. The four LEDs are fixed and mounted in a ring that fits over the viewing tube and may be adjusted for both angle and distance from the subject's eye.

Immediately after the viewing tube sits a fully coated prism beam splitter that reflects the infrared image from the eye at a 90^{o} angle through to the camera mounted above the assembly. This arrangement allows the subject to view the landscape directly since the transmission/reflection ratio of the beam splitter is determined by the incident light at the prism junction, and since no light is incident on this junction from the camera (the viewfinder being blocked). The overall effect is a slightly dimmed view of the landscape, the subject's visual field being limited to 27^{o}, while the infrared image reflected from the eye is simultaneously photographed.

The camera body used is a 35-mm Canon AE-1 equipped with interchangeable f 1.4 50-mm and 100-mm macro lenses. Necessary extension tubes, rings, and a bellows are also available. The 50-mm lens is faster than the 100-mm macro but must be used in conjunction with a Hoya 50-mm closeup lens set (+1, +4). Both lenses are used with an infrared filter and Eastman Kodak high-speed infrared film. The AE-1 will later be equipped with a Cannon Date-Back that allows on-film coding of frames for data identification.

The remainder of the apparatus is constructed around a box that houses the photographic system described and supports the components in the following description.

A large combining glass (80% transmission) is located one meter from the subject's eye. Upon this glass is projected the collimated image of a disc 0.5^{o} in angular extent (about that of the full moon or the sun) that serves as the target stimulus. The subject views the terrain through the photographic system and through the combining glass and sees the target stimulus as a disc superposed on the scene at optical infinity. A second noncollimated source is used to project a similar comparison stimulus upon the combining glass in the same location but exclusive of the target image. This source is equipped with an adjustable full-closure iris that the subject adjusts to match the apparent size of the target image in the experimental conditions.

The comparison image is adjusted in the absence of the terrain scene which is occluded by an opaque light shield positioned beyond the combining glass. When the shield is in position a microswitch is

tripped terminating the target source and triggering the comparison source. Both sources are projected through a prism beam splitter, the arrangement allowing the target and comparison images to be projected on the combining glass at the same location.

Comparison and target stimuli are matched and calibrated to ambient lighting conditions so that the ratio of the image to the scene approximates the illumination of the full moon on a clear night to normal ambient light on a moonlit night.

Portions of the subject's field of view may be occluded by inserting film masks in the line of sight approximately four inches in advance of the photographic system (between the beam splitter and the combining glass). Masks are mounted sheets of graphic art film which at this distance fully cover the 27° visual field and which may be easily constructed to occlude particular portions of the scene. The principal area of interest is the lower visual field and masks are provided to opaque all or various parts and combinations of this area in horizontal, vertical, and radial sections.

In addition, the apparatus is constructed to allow the insertion of a dove prism between the beam splitter and mask carrier. This will allow optical inversion of the scene while controlling for other system variables (orientation, stimulus position, etc.).

In summary, the apparatus described is a portable and versatile device for simultaneous measurement of accommodative state and judged apparent size in field conditions with adequate provisions for occluding selective portions of the subject's visual field.

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Activities and accomplishments are summarized for six research tasks involving various aspects of human performance in the operation of aviation systems. The program has produced information relevant both to the selection and training of pilots and the design of systems and operational procedures.

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